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# Current Trends in Bulk Storage Preservation of Fruits and Vegetables with Emphasis on Tomatoes

RICHARD M. BASEL

The Ohio State University
Ohio Agricultural Research and Development Center
Wooster, Ohio

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# Current Trends in Bulk Storage Preservation of Fruits and Vegetables with Emphasis on Tomatoes

RICHARD M. BASEL[1]

## INTRODUCTION

The concepts of bulk storage preservation have changed in recent years and the current practices need updating. Bulk storage technology will have a great potential influence on the future economic growth of the fruit and vegetable industry. The storage of a perishable commodity is necessary to extend the length of time the processor can produce finished products. Bulk storage preservation technology affords the opportunity for the processor to make a finished product of a number of styles and can sizes based upon consumer need.

### What Is Bulk Storage Preservation?

The term bulk storage is descriptive of processing a commodity for storage, the storage equipment and technology, and how the product may ultimately be readied for processing into a finished food. The bulk preservation of a product necessitates that it be stored in a biologically stable form in containers larger than would be used for finished products. It also necessitates that the commodity can be taken out of storage and processed into finished products whenever necessary. The product may be stored in a non-edible form until final processing is performed. Common storage techniques store food in a "ready to eat" form after a final processing step.

Bulk storage preservation is ancient. Among the oldest forms of storage is drying. This can be performed with many fruits and vegetables. Fermentation of grapes and other foods is also an old means of preservation. Fermentation occurred quite naturally and man had very little knowledge of the underlying principles of microbial action until recent times. Salting was also discovered as an ancient means of preservation. This was an early type of bulk storage requiring additives to facilitate storage. Inhabitants of the northern countries probably first used freezing and chilling in the storage of food. All of these storage techniques prolonged the life of food until it could be utilized. Only in recent history has man's storage technology markedly improved from these primitive methods. Now bulk storage is a common occurrence with many foods. Methods of food preservation can be classified as follows:

- Drying
- Fermentation
- Canning
- Aseptic Storage
- Freezing or Refrigeration
- Chemical Preservative Addition
- Modified Atmosphere Storage
- Acidified Storage

Of these techniques, modified atmosphere, aseptic, and acidified storage technologies developed greatly in the last few years and will be very important to the future of the fruit and vegetable processing industries.

### Need?

The fruit and vegetable processing industry in the Midwest needs new bulk storage technology to extend the processing season if it is to effectively compete with California. Bulk storage technology extends the season and lessens the demand for excessive seasonal labor. Bulk storage also increases marketing flexibility by helping the processor adapt to yearly variations in size of containers and styles of packaging for market demands.

One way to reduce field wastage during the harvest season is to have the capability of storing the commodity until it can be processed into finished products. An initial study on prolonging the storage life of raw fruit did not show much success (7). With the development of controlled atmosphere storage, it might be feasible to store tomatoes and other commodities before processing (15, 76).

Prolonging the processing season by holding the fruit in a partially processed state is an alternative to storing in a fresh state. Seasonality or the availability of a commodity only during a short period can be eliminated, at least partially, by bulk preservation. One way that seasonality in food processing has been reduced is the storage of homogeneous fluids (less equipment will then lie idle after the harvest in a year-round operation). If the processor is to partially process and store, the processor must install labor-saving washing, sorting, and storing equipment for handling large tonnages of the raw commodity during the harvest season. The economics of a bulk storage system must be weighed against the economics of other alternatives.

Aseptic bulk storage of comminuted products may serve as one economic model of the effect of bulk storage systems on the tomato processing industry. The implementation of aseptic systems for storage of tomato concentrates has already made year-round processing a reality (52). This stored product is very susceptible to spoilage. Intricate sterilization systems and procedures have consequently been used to sterilize product and equipment. However, there is a risk of contamination leading to spoilage and economic loss of the materials in storage due to mechanical or human failure. The enormous expenses of capital investment, energy, equipment, chemicals, and labor may make full scale year-round operation minimally profitable as compared to operating a canning facility only during the tomato harvesting season.

Innovations which would make storage of products less expensive and more flexible are sorely needed. One

[1] Former post-doctoral research associate, Dept. of Horticulture.

shortcoming of presently available bulk storage systems is that they are not applicable to the storage of whole fruit. Processing into various finished products from bulk storage would permit full utilization of most processing equipment all year. In addition, it would permit total flexibility of commodities for the market. This advantage alone is highly significant, especially to small processors who depend on higher profit margins to stay in business (73). Bulk storage of whole fruits and vegetables would also permit the processor to package a commodity in a container size that is most profitable. Other economic considerations affecting such a system's rationality have been studied (73).

The following criteria may be used to evaluate the usefulness of storage systems investigated:

- Cost per pound of raw commodity
- The duration of processing into finished goods
- Simplicity of operation
- Flexibility of finished products that may be produced
- Quality of the finished product
- The increase in skilled personnel, reducing the number of unskilled seasonal labor needed

As can be seen, there are many economic considerations that affect a storage system's feasibility. Ureshiro (80) found that given the present economic situation, California should continue to dominate the areas of concentrated tomato pulps and other homogenous products produced from tomatoes. It was postulated that in the production of whole tomatoes there should be fairly even distribution through the country. One way this can occur is by putting the raw commodity into bulk storage. A hypothetical result given by Sullivan (73) is that individual plant size would increase, thus decreasing the number of processing plants. It is hoped that in the future, bulk storage technology will be suited to the smaller processor such as is found in Ohio by requiring less initial capital investment to start bulk storing raw fruits and vegetables.

### Scope and Objectives

Current practices of controlled atmosphere bulk storage and aseptic bulk storage are examined. This bulletin endeavors to explain the theory, current practice, and ramifications of each type of storage. A new method for acidified storage of whole fruits and vegetables is introduced. This should enable the processor to decide which method may be most applicable to his situation. Where possible, examples are used that apply directly to the tomato processor, primarily because tomatoes are the largest crop envisioned to be bulk stored by these methods in Ohio.

## WHY BULK STORAGE?

The reason for the rapid development and implementation of bulk storage technology has been to prolong the processing season. The needs of bulk storage are that the product must be pre-processed in large (preferably reusable) bulk containers and held until requested for final processing into consumer containers. If one were to merely store the commodity, it would quickly spoil and be rendered useless. Therefore, bulk storage becomes a viable storage technique only if large amounts of the raw product can be stored at low cost with resultant good finished product quality requiring a minimum of further processing. If a great deal of processing becomes necessary before storage, the use of bulk storage will not increase yearly production without increasing plant size. In order to evaluate the quality of stored products, it then becomes necessary to understand the mechanisms that can lead to their deterioration.

### Chemical Deterioration

Deterioration due to time-temperature dependent reactions of the food constituents has been thoroughly studied. These reactions include deterioration by oxidation, photooxidation, temperature, and enzymes. Chemical deterioration of this nature can be controlled depending on the bulk storage system utilized.

One well-known defect in stored fruits and vegetables is oxidation. Oxidation is simply the insertion of the element oxygen into a food component molecule from either oxygen gas or by reaction of an oxygenated species. While oxidation of lipids is well known in foods, most fruits and vegetables have a small relative portion of their constituents comprised of lipids.

The most common oxidation problems in fruits and vegetables are from the enzymatic browning and browning reactions of sugars. Enzymatic browning can be inactivated by heat. These browning reactions impart a dark color and off flavor to the product which is distinctive. There are two main types of browning reactions found after heating fruits and vegetables: the caramelization reaction and the Maillard reaction. Some ways of limiting browning reactions include the exclusion of oxygen, the lowering of temperature, and decreasing the length of storage. The most effective way of dealing with this problem is by using a temperature ranging from ambient to just above freezing and utilizing an oxygen impermeable container. Natural antioxidant constituents such as ascorbic acid are very susceptible to this problem.

Photooxidation of various components can occur rapidly. Light catalyzes many deterioration reactions, such as photooxidation which results in both artificial and natural changes in either darkening or lightening in color and changes in flavor. In order to minimize light mediated changes, storage systems must exclude light.

Temperature of the product is very important to the keeping quality of the stored product. It can affect almost all important deterioration reaction rates. Temperatures employed in bulk storage range from room temperature to just above freezing. The rate at which deterioration occurs is diminished at lower temperatures. Freezing temperatures should never be used to store whole fruits and vegetables since ice crystal formation during freezing and thawing results in loss of firmness within the commodity.

Enzymatic deterioration is of major concern to the food processor. Enzymatic changes can lead to loss of quality such as softening and off flavors in stored tomatoes (21). These changes are most easily averted by some type of blanching or enzyme inactivation technique. In processes where the product is heat treated, enzymes can be inactivated at the same time that microorganisms are destroyed.

### Microbial Spoilage

Spoilage due to microbial attack is an important problem in fruit and vegetable storage. Microbial attack can additionally lead to disease or food poisoning.

One of the first ways food may be altered is by the fermentation of fruit and vegetable constituents. The organisms generally alter the food by utilizing fermentable compounds for energy and producing end products from these reactions. Carbohydrates are the most commonly fermented constituent of fruits and vegetables. These are usually in the form of sugars such as glucose, fructose, or sucrose. These sugars are fermented into end products such as acetic acid, lactic acid, or a mixture of fermentation products. Proteins and amino acids can be metabolized by some organisms. The result of protein fermentation is usually a putrid type odor. In addition, many other odors and alterations may occur due to minor quantities of metabolic products being produced by the organisms. A few organisms of special importance will be discussed since knowledge of them is important to successful bulk storage.

Lactic acid bacteria are probably the best known of food spoilage bacteria in fruits and vegetables. These organisms have complex nutritional requirements and may require amino acids (34), pantothenic and/or nicotinic acid (69), and cofactors for nucleic acid synthesis (23). These bacteria are prominent fermentative organisms found in non-thermally processed fruits and vegetables (63). They are gram positive facultative rods and cocci that can convert reducing sugars into lactic acid and/or other end products without utilizing oxygen. These bacteria can be divided into three important genera: *Leuconostoc, Lactobacillus,* and *Pediococcus.* All are easily inactivated by heat (57), but require a low pH ($< 3.5$) to inhibit growth if not subjected to heat.

The Bacillaceae are rod shaped bacteria that form heat-resistent spores. One very important spoilage organism is *Bacillus coagulans.* This organism is very heat resistant (70, 86). By pasteurizing or high temperature short-time processes, spores of this acidiphillic bacilli can be destroyed.

Flat sour *(Bacillus coagulans)* spoilage of fruits can be most easily reduced by washing the fruits (50). Another method of inhibiting flat sour spoilage is by lowering the pH to 4.0 or below (87). The growth of *Bacillus coagulans* is reduced by lowering the oxygen concentration (58). This concept is of use in many bulk storage systems.

Organisms in the genus *Clostridium* are notorious for problems caused in fruit and vegetable products. *Clostridium botulinum* is probably the best known of these. They grow in anaerobic environments if the pH is not kept below 4.6 or the product is not sufficiently heat treated to kill the spores. *Clostridium pasteuranum* and related organisms are acid tolerant. They survive at a pH as low as 4.0 to 4.1 (17). Spoilage due to *Clostridium* spp. is usually easy to detect due to the putrid odor, but must be eliminated in food because of its food poisoning potential.

Fungi can also be encountered in spoilage of bulk storages. This is the group of organisms that are usually known as "mold". When a commodity such as tomatoes enters a processing plant, it may be contaminated with many organisms (29). Genera of importance include *Aspergillus, Alternaria, Colletrichum, Fusarium, Penicillium, Pythium,* and *Geotricum* (24). These organisms utilize reducing sugars as carbon sources. They are inhibited by anaerobic conditions, yet are extremely resistant to a wide range of pH and water activity. They are usually easily destroyed by heat treatment.

Yeasts are closely related to the fungi and also may be an important spoilage problem, especially when the food contains fermentable sugar. They are single celled organisms usually capable of anaerobic growth, and are difficult to kill with chemical sterilants. Some of the typical spoilage yeast genera found in association with tomato processing are *Candida, Debaryomyces, Hanseniaspora, Kloeckera, Pichia,* and *Saccharomyces* (84). Yeast fermentation usually gives rise to ethanol, $CO_2$, and a characteristic odor during fermentation.

The microbial load on the fruit or vegetable is usually the source of most organisms entering the food processing unit. In order to cleanse the fruits of all these organisms, detergents, agitation in elevated temperature water, high pressure rinses, and possible immersion in disinfectants have been proposed (33). However, viable organisms were reported inside of fruits and vegetables even if the outside surface was disinfected (63).

Microorganisms such as lactic acid bacteria, bacilli, yeasts, and fungi were reported to enter into normal, healthy, undamaged fruit tissue. Microorganisms within the tissue were theorized to live in association with the fruit (62). While the microorganisms within the tomato do not normally present a problem, when the tomato is stressed, injured, or macerated, the microbes within the fruit may quickly multiply and cause spoilage. Therefore, careful handling is important if the fruit or vegetable is to be held in post-harvest storage.

## POST-HARVEST STORAGE PRIOR TO PROCESSING

The theory of post-harvest storage is to preserve a fruit or vegetable in its raw or unprocessed form. This can be accomplished by changing the environmental conditions to reduce respiration. There are two types of post-harvest storages. In one method the enzymatic and microbial activity is halted by using a gas sterilant. The other type of storage uses gases to inhibit respiration of the commodity. This is already applied to some fruits as in the controlled atmosphere (C.A.) storage of apples for year-round processing or marketing.

Post-harvest storage methods have been studied since the 1920's when Kidd and co-workers investigated fruit storage (42). This field of study has become very important in the last decade. Fruits and vegetables have historically been grown in areas of high yield and have either been processed at the time of harvest or sold as fresh produce. As a consequence of processor and consumer desire for these products after harvest, interest in post-harvest storage has gained enthusiasm. As a result, various types of atmosphere modification techniques have been developed.

Atmospheric generation was developed to lower the oxygen partial pressure by various methods and has been reviewed by Smock (68). Hypobaric systems are effective because they lower the atmospheric pressure in the commodity by vacuum to effectively lower partial pressures of individual gases (20, 37). Modified atmosphere storage describes systems where the amount of the gases in contact with the commodity are precisely controlled to limit respiration. With this system, purified gases such as carbon monoxide are easily introduced (60, 61, 68). Hyperbaric storage has recently been reported as a possible way of storing fruits and vegetables (59). In this method very high gas pressures are used. These high pressures are capable of inhibiting respiration and enzyme activity. Hyperbaric storage also enables safe elevation of enzyme poison levels such as carbon monoxide.

Another method has been to use gas exchange for preserving and extending shelf life of raw foods (43). This method, however, results from the action of preservative gases on fresh fruits and vegetables by inactivating enzymes and spoilage microorganisms. This contrasts sharply with post-harvest treatments of enzymatically active fruits and vegetables.

In order to fully understand how each of these methods works, each one will be covered separately to show the processor how to diagram the specific storages. Where possible, tomatoes will be used as an example even though they may not be an economical commodity to store in some systems.

## Atmospheric Generation

Controlled atmospheric generation systems have in common the fact that oxygen has been limited by some technique. Some of the simplest approaches are purging the chamber with nitrogen, using combustion techniques to lower oxygen, or converting the oxygen to $CO_2$ via a catalyst (75, 88). Fresh market produce has been packed using plastic and various types of oxygen exchange barriers in order to limit oxygen during transit and storage on the shelves (31).

In some modern systems, water, calcium carbonate, or molecular sieve material has been used to remove carbon dioxide ($CO_2$) and the amount of oxygen ($O_2$) that is needed can be added from fresh air (61, 68). Carbon dioxide and carbon monoxide (CO) can be added if needed from pressurized cylinders. A recent method for altering $CO_2$ uses charcoal absorption (49). One common type of experimental atmospheric generation unit is shown in Figure 1.

Another function of atmospheric equipment may be the removal of ethylene. One type of ethylene scrubber that has been employed with stored flowers uses potassium permanganate, calcium hydroxide, and water (27). More work is needed to develop systems that absorb volatiles such as ethylene, a hormone which influences senescence. This development would lead to the expanded use of atmospheric generation for preservation of fruits and vegetables.

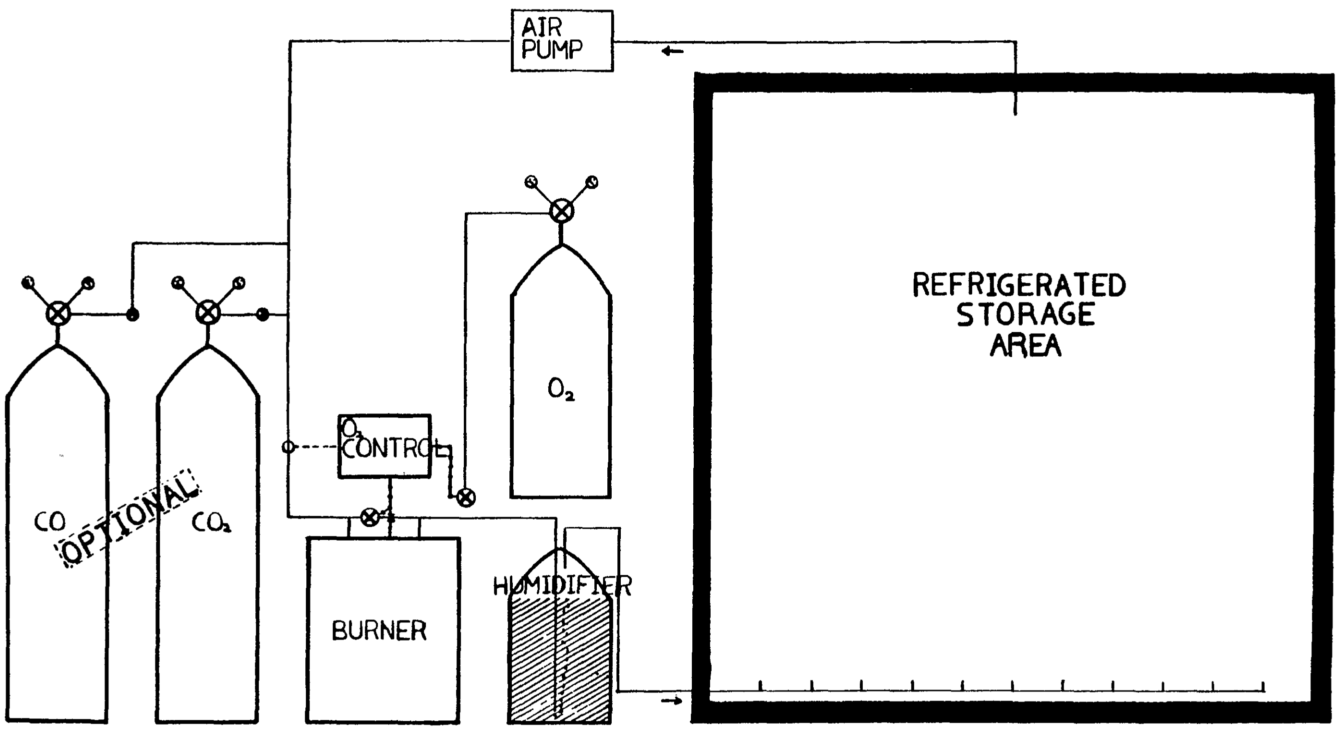


**FIG. 1.—An atmosperic generation bulk storage unit.**

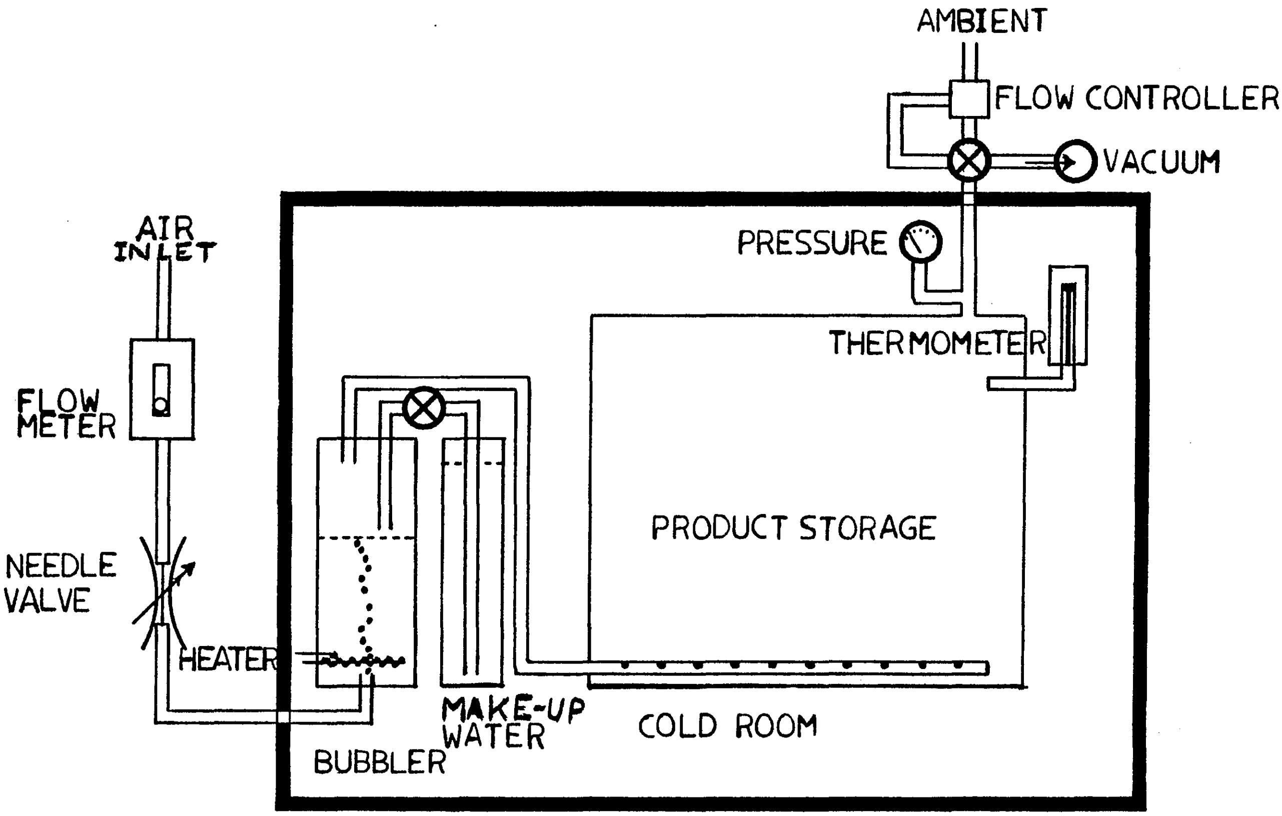


**FIG. 2.—A hypobaric bulk storage unit.**

The use of atmospheric generation may also be incorporated into other systems such as modified atmospheric storage and storages where the pressure used is not atmospheric. The use of an atmospheric generation system could be used with sorted and sanitized tomatoes to hold them a few weeks for later processing. This would be a relatively inexpensive system to maintain once built. However, it would not offer the long storage times reported for other types of post-harvest storages.

## Hypobaric Storage

Hypobaric storage is basically reduced pressure storage; thus, a one-fifth atmosphere storage would produce an effective oxygen concentration of 4% at normal atmospheric pressure. This treatment also can help remove volatiles such as ethylene, but water is also removed. In order to counteract this problem, makeup air must be saturated with water or the commodity will dessicate. A hypobaric storage system is shown in Figure 2. This system is very costly to construct because there must be a chamber capable of withstanding high pressure differentials. These chambers probably may not be feasible for the large quantity of tomatoes to be stored for the processor once a year. It has been a good experimental tool for understanding the post-harvest physiology of tomatoes and other vegetables. In products where there can be year-round use and a high profit margin, such as fresh market product, this method may be useful. The proper conditions for storing various products have recently been reviewed (37, 47).

## Modified Atmosphere Storage

Modified atmosphere storage works by controlling the gas mixture used for contact with the commodity. This technique incorporates the principles in atmospheric generation. If atmospheric generation techniques are incorporated, it is possible to reduce the amount of harmful metabolic products produced and limit the amount of makeup gas required for air exchange. A modified atmosphere storage may be constructed as shown in Figure 3. Respiration can be affected by adding such gases as $CO_2$ and CO. CO is quite hazardous unless proper precautions are taken, but CO markedly improves the storage of tomatoes (11, 41). CO can act on the tomato as an ethylene analog and as an inhibitor of cytochrome oxidase (1, 18). It can also suppress many organisms except *Geotricum* (28, 85).

Red ripe field run tomatoes stored best in an atmosphere of 4% $O_2$, 5% $CO_2$, and 11% CO (11). Storage for 4 to 8 weeks can be expected with current technology for tomatoes. This length of time would be sufficient to hold raw products past the peak harvest period of many fruits and vegetables. Specific modified atmosphere storage parameters to be used for many fruits and vegetables have been detailed (20, 40, 61, 79).

## Hyperbaric Storage

One of the earliest studies with hyperbaric storage showed a decrease in respiration at 4 atm. (8). In order to maintain quality of cereal grains, hyperbaric storage has been proposed (51). In this system it is possible to

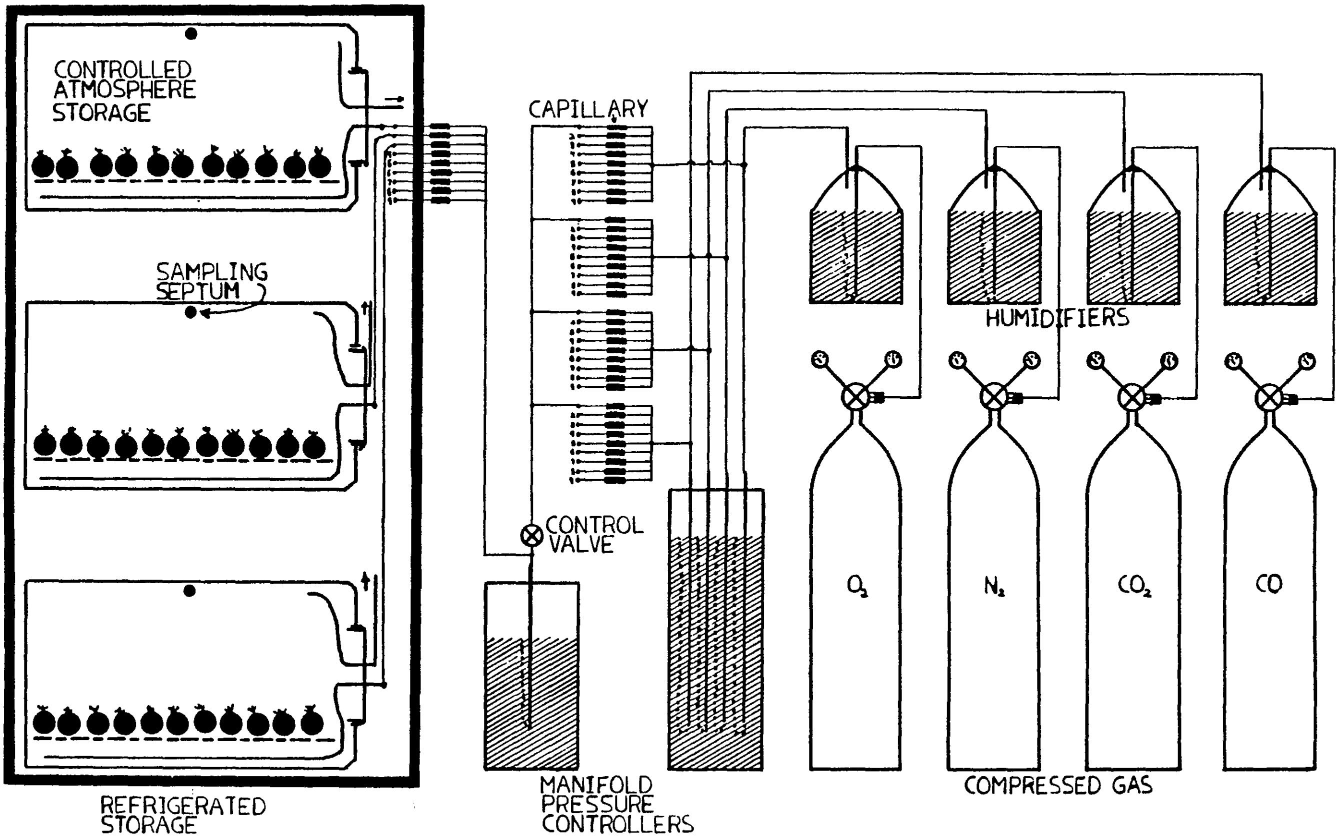


**FIG. 3.—An experimental modified atmosphere bulk storage unit.**

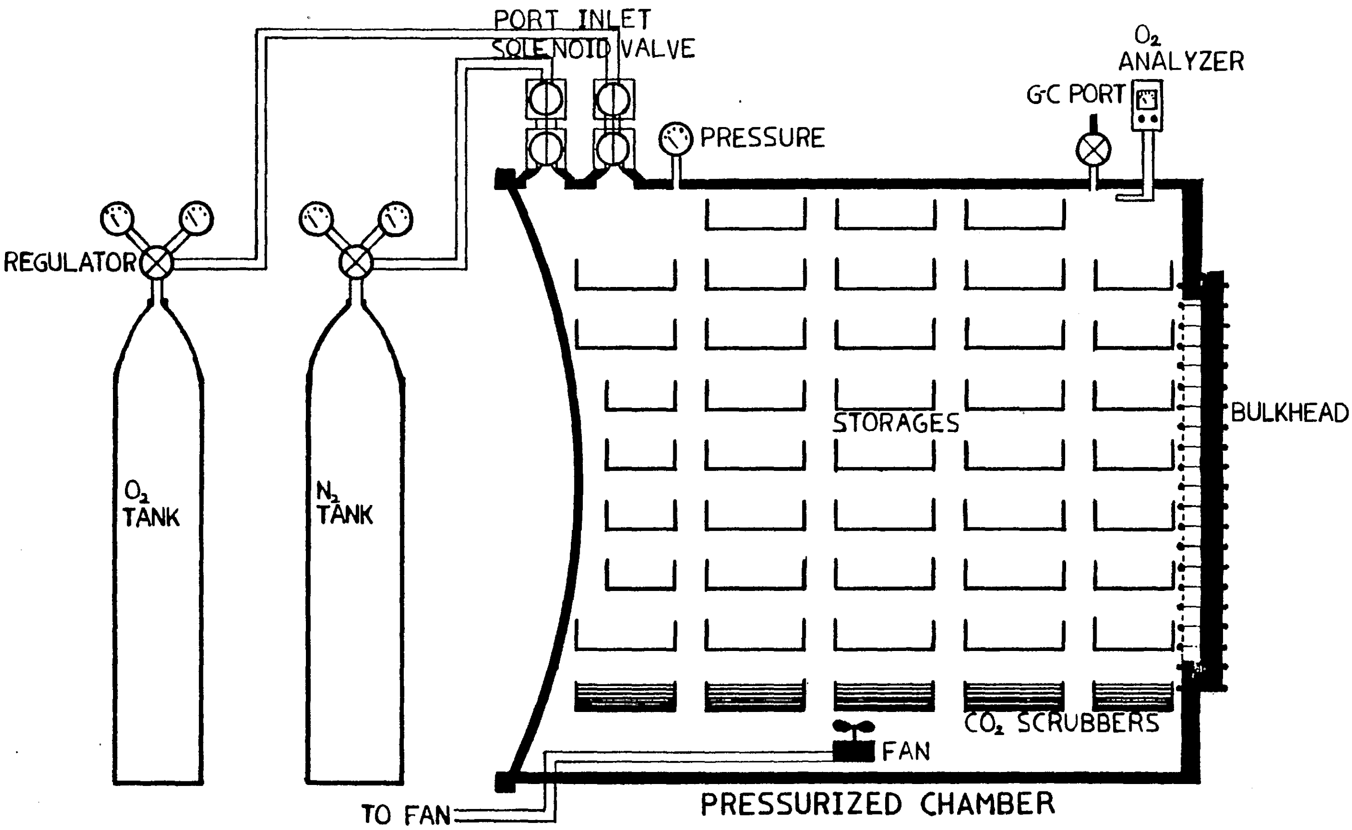


**FIG. 4.—An experimental hyperbaric bulk storage unit.**

maintain cold temperatures and high pressures by submerging the product in water. At very high pressures, enzymes and microorganisms are inhibited (22, 65). It has been possible, however, to study storage at high pressure with an experimental chamber (59). This experimental storage is shown schematically in Figure 4. This type of chamber has been ideal for the study of different gas mixtures under high pressure. This method, although still only experimental, may have great future potential for storing certain fruits and vegetables. Deep bodies of water, *i.e.,* lakes and oceans, make ideal storage chambers where high pressures may be easily maintained at temperatures near 4° C.

### Gas Exchange Preservation

This process is an extension of controlled atmosphere storage that uses the preservative action of certain gases (43). It is different from controlled atmosphere storage in that the biological activity of the raw food is inactivated. While this method is not yet commercially available because of restrictions on the use of ethylene oxide (EO) and sulfur dioxide ($SO_2$), it represents an important frontier in bulk storage that may have a future impact. This method works by simple gas exchange of nitrogen ($N_2$), EO, and $SO_2$ as shown in Figure 5. The products stored in this manner have exceptional quality and can be stored in that condition or manufactured into any finished food desired (43).

Raw Fruit and/or Vegetables

↓

Air Evacuation

↓

100% Nitrogen

↓

Flush with Carbon Monoxide

↓

Flush with Ethylene Oxide in Carbon Dioxide

↓

Flush with $SO_2$

↓

Flush with CO or $CO_2$

↓

Store at room temperature
until needed

**FIG. 5.—Unit operations of gas exchange preservation.**

### Applications of Post-harvest Storage

At present the technologies discussed have been used primarily with fresh market products. One reason is that these products may be able to assume more storage costs to offset transportation costs of interstate competition. Hopefully, as this technology progresses, many processors will be able to utilize it. Some controlled atmosphere stored products such as apples, potatoes, carrots, and celery are being used to a degree by processors. With these bulk storage methods, the greatest spoilage problems include mold growth, softening, and dessication. For each commodity stored, there are different optimal conditions. The storage conditions producing the highest quality post-storage product must be investigated for each specific commodity in order to be competitive.

The most profitable time to use post-harvest storage is when a processor wants to add a small amount of a fruit or vegetable to manufacture a product. For instance, a manufacturer may want to store mushrooms as a minor ingredient for a meat-based soup. It would also enable a processor to take in a large amount of a raw commodity. Since he has the ability to turn the product into finished merchandise, he may use it as a hedge against market demands for high profit items. Gas exchange preservation may hold the greatest potential to the processor in the long term. It promises to be inexpensive, simple, and give good quality to the finished goods (43).

## THERMAL PRESERVATION BULK STORAGE

The principle behind all thermal preservation processes is the same: namely, to apply heat in a sealed environment in order to inactivate enzymes and destroy any potential spoilage organisms. Canning is still the most common method of thermal preservation. In canning, a food product to be preserved is placed into an open container, a vacuum is created, and the package is sealed. Then the product is heated sufficiently for a proper thermal process. With products that have a pH above 4.6, it is necessary to heat by using pressurized steam. In recent years, a continuous system of heating and storing has emerged for comminuted products. This process uses continuous high pressure heating and cooling via heat exchangers. After the product is sufficiently cooled, it is pumped into a sterile tank. The product is maintained in the tank with a sterile gas head space. In thermal preservation, the important criterion is the application of sufficient heat to destroy spoilage organisms and render the product safe in a container that is closed to the outside environment to prevent recontamination.

### History

Spallanzani, in 1765, found that food could be preserved by application of heat. The process was first devised and outlined for various foods by the Frenchman, Nicolas Appert, in 1809. He is considered to be the father of canning as he was the first one to show that foods could be bottled in a sealed container to prevent spoilage. He was the first person to recognize the need for a hermetic seal.

In 1810, Peter Durand is credited with the development of the tin can. Isaac Solomon is responsible for the major breakthrough of using calcium chloride to raise the boiling point of water. Then A. K. Shriver invented the closed retort in 1824. This basic technology is still used today for canning of many foods.

The tin can was not very well suited to storing large tonnages of bulk unfinished product. Cost of non-reusable containers and labor involved in handling the product are restricting factors. Therefore, a new system was needed in order to store unfinished goods. This was the impetus for the aseptic bulk storage method. The aseptic bulk storage method used by the H. J. Heinz Company was among the first used commercially. In 1963, the first patented aseptic bulk storage system was described (26). The first reports of tomato product storages included stainless steel tanks, bacteriological air filters, and 3-way valves (14, 16). These valves were sterilized before filling and a 3% caustic soda solution was used to exclude microbial contamination after filling. With products such as apple and grape juice, quality "equal to or superior" to conventionally stored juice was reported (44). The sterilization of the tanks can be performed with compounds such as hydrogen peroxide, iodine, or perchloroacetic acid (32, 89). Special valves for aseptic bulk storage are used to insure the sterility of the system (53). These developments have led to aseptic bulk storage being widely used for the storage of many types of concentrates.

## State of the Art Aseptic Bulk Storage

Aseptic storage has been adopted by many corporations for the storage of homogeneous concentrates and single strength comminuted products. In order to aseptically bulk store food products, the following criteria for aseptic processing equipment must be met (4):

- The equipment must be sanitary
- The equipment must be capable of being initially sterilized
- The equipment must be capable of being maintained in a sterile condition
- The equipment must be capable of operating in an efficient manner
- The equipment should be designed for the application of clean in place (CIP) techniques
- The equipment must be designed to conform to existing safety codes
- The equipment must be designed to comply with regulatory or other legal considerations if they exist

To understand the advantages and disadvantages of this system, it is useful to examine each criterion separately. The use of sanitary equipment (*i.e.,* equipment that can be cleaned and maintained without microbial contamination) is necessary so that a sterile environment may be achieved. This means that equipment and product must be capable of being easily cleaned, sterilized, and kept in a sterile condition. Salient features for aseptic storage must be strictly followed in designing such systems (35).

One of the major problem areas with bulk storage has traditionally been contamination of the valves. Although very simple systems such as covering conventional valves with a plastic bag fitted with disinfectant solution will work (9), more elaborate and "fool-proof" aseptic valving systems have been developed for use with aseptic bulk storage (53). Tank design for bulk storage is also an important consideration. As a result of interest from industry, sanitary standards for silo-type storage tanks have been developed (6).

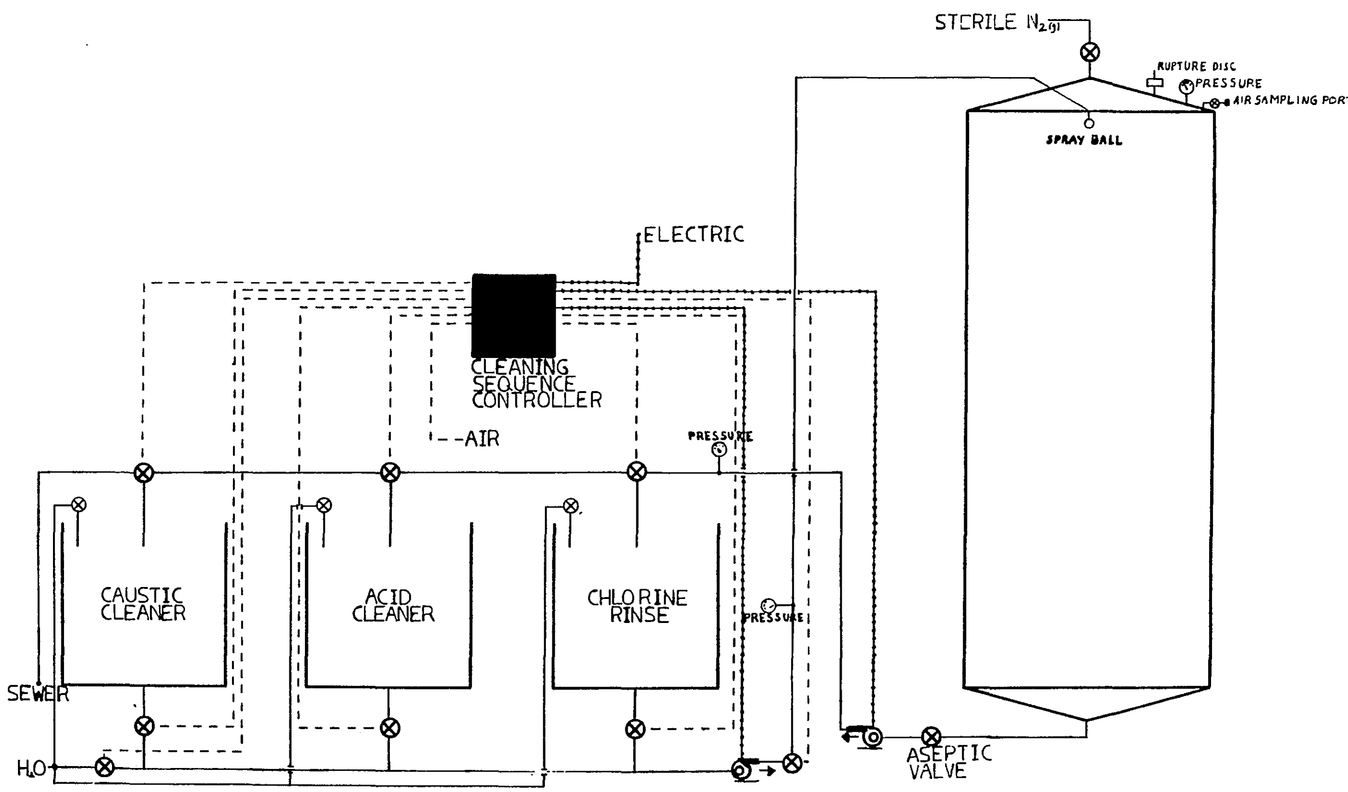


**FIG. 6.—Clean in place systems for preparing bulk storage tanks.**

For any aseptic system, the equipment must be capable of being sterilized. Clean in place (CIP) systems have been designed (67). A typical CIP system is shown in Figure 6. Iodine solutions are predominantly used to sterilize tanks (5, 77). At 21 ppm, iodine solutions are capable of rendering equipment sterile after a few hours of contact time (5). Steam and other methods of heat sterilization are problematic, because water layers are formed in equipment so that sterilization may not be complete (36). In using chemical sterilants, the greatest problem is insuring contact of 100% of the processing equipment surface area.

CIP cleaning systems use automatic or pseudo-automatic cleaning regimes. Tank sterilization is usually performed via spray balls installed permanently in a tank. These spray balls facilitate cleaning. These cleaning fixtures can later be sealed off and sterilized concurrently with the tank. After the cleaning cycle, the normal sterilization regime is to flood the tank completely with iodophores. The iodophore is subsequently removed after contact sterilization while a head pressure of sterile filtered nitrogen gas is applied to the tank (67). If filtered air was used, a small amount of browning due to food oxidation would result. Additionally, if any organisms are introduced into the storage during emptying, there would be a risk of contamination.

The equipment for continuously heating and cooling the product must be designed for sterilization. Steam, hot water, or iodophore solution can be used to sterilize this system. Steam can condense in the lines and equipment and lead to inadequate sterilization. Probably the best method is super heated water at a temperature of approximately 240-250° C circulated under pressure.

Once sterilized, the equipment must be so designed to heat sterilize the product. A typical aseptic bulk storage system is shown in Figure 7. When products are of high viscosity, such as tomato juice, a scraped surface heat exchanger must be used. A most important design consideration is the adequate application of positive pressure on the system. If a vacuum develops in the aseptic system, there is a risk of contamination. A back pressure valve may be used to maintain a correct positive pressure during filling of tanks. There must be sufficient instrumental control so that underprocessed product does not enter the sterile section of the system. This can be accomplished by using flow diversion valves at critical control points in the operation. When the temperature of pressure critical control points drops below preset limits during sterilization, the valve would divert the product flow and sound an alarm to alert personnel. These procedures should generally insure that the product is sterile. Any deviations in the process cannot be treated as thermally processed hermetically sealed containers. Any time or temperature deviation in the process past the non-return valve represents a potential leak in sterility. All product and/or containers from such a processing operation need to be completely

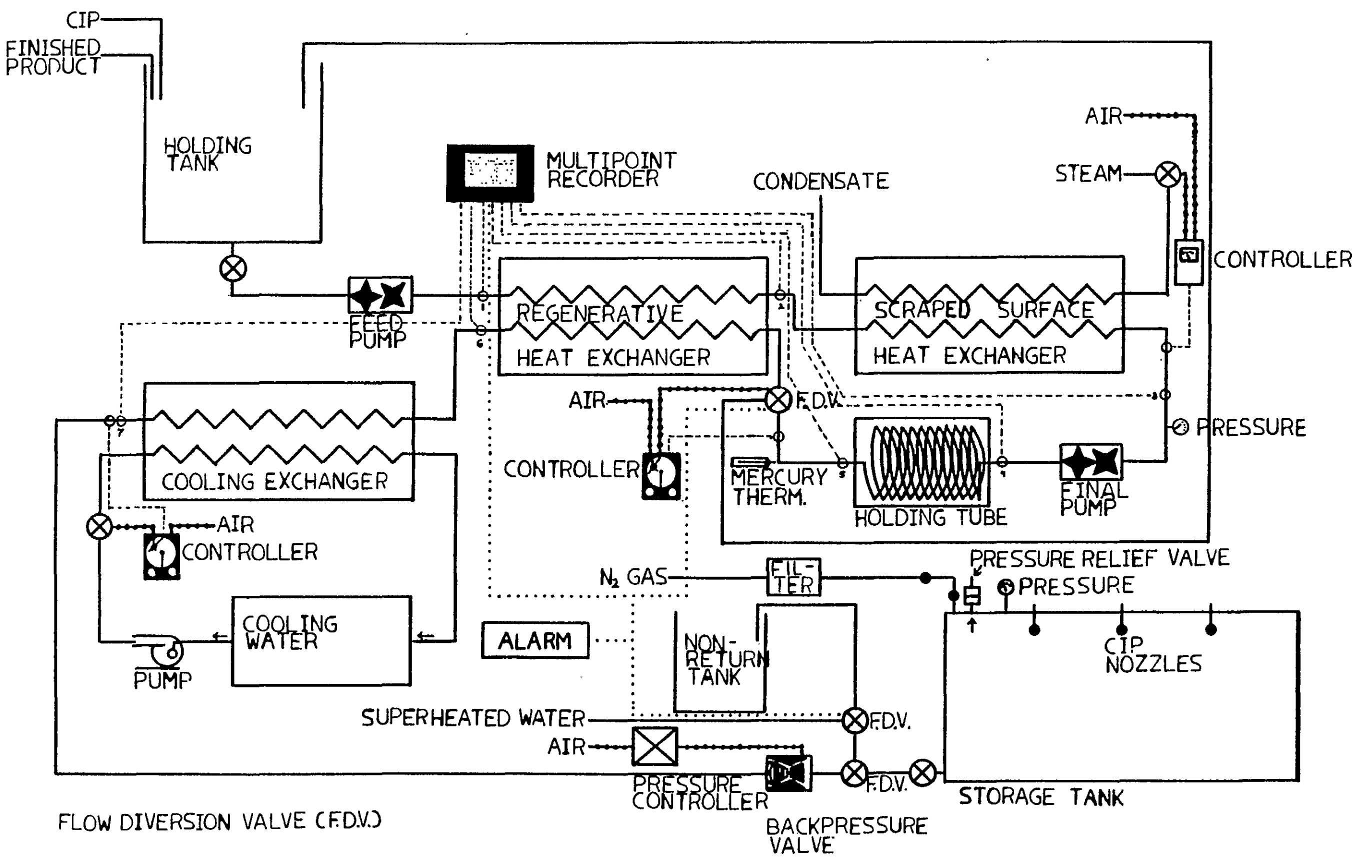


**FIG. 7.—A typical aseptic bulk storage system for storage of comminuted tomato products.**

reprocessed or discarded with low acid foods for safety reasons (38). This problem is one of the principal concerns unique to aseptic techniques.

Equipment can be maintained in a sterile condition if engineering is correct (6). Proper engineering will insure that equipment can be efficiently operated.

The operation of an aseptic storage system can be quite technical and involves many procedures. Hulsey (35) outlined an operation procedure for aseptic bulk storage.

Once the product is stored in the tank, it can be held until needed either for shipment or final processing.

### Quality Control in Aseptic Bulk Storage

In aseptic bulk storage, quality control is extremely important. This system requires sound quality control as the introduction of any viable spoilage microorganisms can lead to a quick and possibly total economic loss of product. Since so much product is at a risk in one storage vessel, this problem should not be underestimated.

Instrumentation is a necessity to monitor temperatures along the holding tube. Additionally, safeguard instrumentation should signal an alarm and switch the flow diversion valve (Figure 7) in the case of an improper process. Another important consideration is the recording of backpressure while filling and monitoring tank pressure readings in a finished tank. An increase in tank pressure can be an indication of a spoilage problem.

Another type of quality control involves the direct monitoring of contamination. This can be done by direct culturing for microorganisms or present day rapid methods of detection (55). Specific culturing should be related to the product stored (71). The filtered headspace can be sampled for contamination using a Millipore filter or other techniques (3).

Some new methods are much faster than pour plate culturing techniques and have been applied to bulk storage (55). Techniques based upon products of fermentation have been developed for rapid detection of spoilage (13, 48). It is hoped that further improvements will be made in analytical procedures to detect contamination in bulk storage.

### Applications of Aseptic Bulk Storage

Aseptic bulk storage is an important bulk storage method for comminuted products such as tomato, apple, grape, and citrus concentrates.

A major limitation is that existing aseptic bulk storage requires a homogenous liquid product and is very expensive from an initial investment standpoint. This technique will likely remain the method of choice for homogenous liquid bulk storage products.

## ACIDIFIED BULK STORAGE

Another technique to inhibit microbial spoilage is to acidify the product. Acids are one of the end products of fermentation. Acidic end products can inhibit spoilage organisms from developing. This principle has been used for many years to preserve products such as pickles. Vinegar is also used to acidify foods, *i.e.*, salad dressings, catsup, soup.

Bacteria are among the easiest microorganisms to control using acidified bulk storage. Anaerobes present in tomato products can be inhibited by reducing the pH to 4.0 (17). With the same adjustment of pH, potential *Bacillus* contamination can be eliminated as a spoilage threat in tomato products (78). The most acid tolerant genus, *Pediococcus,* grows at a pH as low as 3.24 (56).

Fungi are more acid tolerant than bacteria. Some species can easily grow in an environment with a pH of less than 1.2 (84). These acid tolerant fungi are obligate aerobes. Therefore, their growth should be completely eliminated when the oxygen is depleted.

The most acid tolerant organisms growing in fruit and vegetable products are yeasts. Since yeasts have end products that are non-acidic from respiration, they do not add greatly to the acidity. They are defined as "single cell budding stages not possessing mycelia and usually capable of anaerobic growth" (72). Therefore, mere exclusion of oxygen is not successful in eliminating yeast growth. Common fermentation by yeasts results in the production of ethanol, acetaldehyde, and large amounts of $CO_2$. These compounds do not contribute appreciably to the pH if acidified bulk storage is used (10).

In acidified storage, a non-growth threshold for yeast was investigated as a starting point for bulk storage. Suspected yeast genera growing at low pH in tomatoes included *Saccharomyces, Candida, Debaryomes, Hanseniaspora, Kloeckera,* and *Pichia* (84).

Microorganisms are not the only important consideration of bulk storage techniques. Enzymatic activity must be eliminated at low pH to inhibit formation of undesirable metabolic products. One of the more acid stable enzyme systems should be that of tomatoes since they have an internal pH of about 4.3

Acidification with hydrochloric acid (HC1) increased consistency in tomato products (2, 83). There has been work on enzyme inhibition in tomatoes using acidification (82). It was found that a pH of 1.63 was necessary to inhibit enzymes affecting consistency in unheated tomato juice. It is presumed that enzyme inhibition by lowering pH results from enzymatic pH rate dependence or possible denaturization of enzymes (66).

Acids may affect microorganisms by many mechanisms. Organic acids such as acetic acid are toxic to microbes (46). This toxic effect is due to factors other than pH. With many organic acids, the molecule exhibits toxicity that is independent of its effect on pH. This may be due to end-product inhibition of fermentative enzymes. Organic acids such as acetic, lactic, or citric acid can be referred to as microbial waste products of fermentation. For instance, 2% acetic acid will destroy *Pseudomonas aeruginosa* in 15 minutes. Numheimer and Fabian (54) showed that acids can be placed in decreasing order together with their dissociation constants: acetic, citric, hydrochloric, lactic, malic, and tartaric. The addition of an organic acid that is also a fermentation end product to a raw fruit or vegetable can be more toxic to microorganisms than an equivalent amount of inorganic acid.

Since inorganic acids have a much higher dissociation in water, they would be of use in storing fruits and vegetables because a smaller quantity produces the desired change in pH. Some inorganic acids, such as hydrofluoric acid, have special germicidal properties (64), but should not be used because they are very toxic to humans. An economical inorganic acid such as HCl would be a good choice owing to its simplicity and the fact that it does not introduce any non-declared additive to the finished product. Hydrochloric acid is also responsible for some of the digestive action in the stomach of man and therefore is regarded as safe.

## History

Acidified storage using vinegar (acetic acid) has been practiced for many years as a method of preservation. It can be used to store cucumbers and many other types of pickled products. One method of preservation that had been tried was the addition of hydrofluoric acid to fruit juices (64). Hydrofluoric acid was toxic in the acid form and it had to be completely removed at the end of storage by salting out as calcium fluoride. This method only could be applied to liquids. Another attempt to use acid for preservation was the addition of phosphoric acid and sodium sulfite (74). This method imparted an $SO_2$ taste and odor and could not be used with many products because of regulations against the addition of $SO_2$ to many foods. Another method using lactic acid addition is useful for the sterilization of juices and syrups (81). This method may add too much lactic acid to be useful in other applications. Hydrochloric acid has also been used in the past to help preserve fruits and vegetables (19, 30).

The methods using addition of acids mentioned above require heat treatment. An acid treatment is used merely to help reduce the heat treatment needed. The first use of an acidified bulk storage using HCl without a heat treatment was described by Basel and Gould (12). This method facilitates storage of whole fruits and vegetables for later processing. This new method represents the first bulk storage system that can store whole field run tomatoes for periods up to a year. When neutralization is accomplished, an end product of sodium chloride results which is normally added to tomatoes in processing. Although there has been work done that shows promising results with other crops, the ensuing data and discussion will be limited to tomatoes.

## Principles of Acidified Bulk Storage

Before one can bulk store tomatoes, it is necessary to determine how much acid is needed to prevent spoilage. It was found that a pH between 1.30 to 1.34 or less was necessary in order to store whole tomatoes (Table 1). When whole products such as tomatoes are stored, it was found that a few weeks of storage may be required to reach an equilibrium pH. Titration with sodium hydroxide and measurement of the salt demonstrate that a reasonable amount of salt is formed after neutralization (Figure 8). The acid must be neu-

**TABLE 1.—Effect of pH on Spoilage in Acidified Bulk Storage.**

| Equilibrium pH | Percent of Spoilage | Average Time until Spoilage | Organisms Responsible for Spoilage |
|---|---|---|---|
| 2.00 | 100% | 1 week | yeasts, mold |
| 1.80 | 80% | 1 week | yeasts, mold |
| 1.60 | 75% | 1 week | yeasts |
| 1.40 | 50% | 1 month | yeasts |
| 1.35 | 5% | 1 month | yeasts |
| 1.30 | 0% | — | — |
| 1.25 | 0% | — | — |
| 1.10 | 0% | — | — |
| 1.05 | 0% | — | — |

tralized by careful addition of sodium hydroxide to a given pH. This neutralization takes up to a few days and has been accomplished at refrigerated temperatures.

It was necessary to consider the role of oxygen in color changes of tomato products held under acidified bulk storage. Oxygen in the storage can cause a deterioration in the color values (Figure 9). This color change was evident as darkening and more severe at elevated temperatures. Concurrent with a deterioration in color was a decrease in ascorbic acid content and flavor score (11).

If it is necessary to exclude oxygen from the storage, it may also be important to exclude oxygen from the

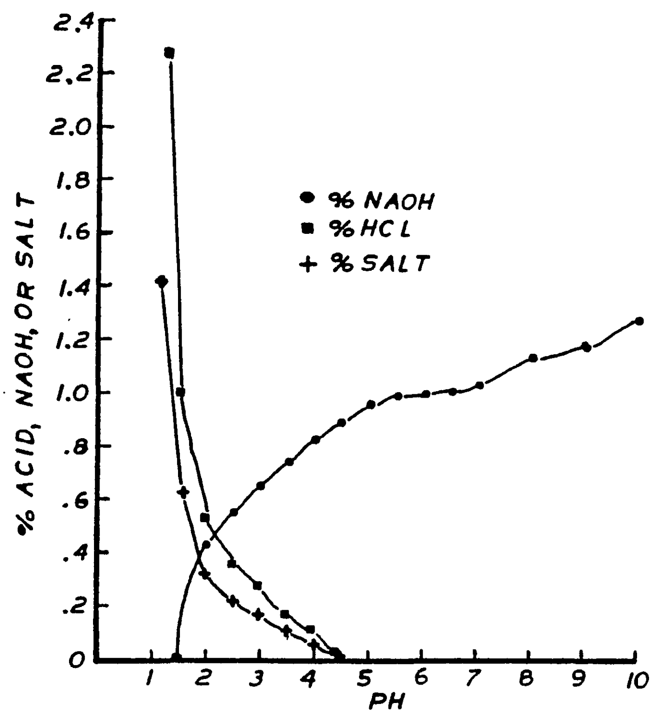


**FIG. 8.—Titration curve with 1 N sodium hydroxide or 1 N hydrochloric acid and showing the amount of salt produced at acidification with various pH's.**

tomatoes before storage. However, it was found that there was no difference in quality by pretreatment with either blanching or evacuating the $O_2$ to limit the oxygen degradation. Since the raw tomato is a live respiring plant tissue, it was suspected that most oxygen in the tomato was consumed by respiration before the equilibrium pH was obtained. It takes approximately 1 week for the tomato to adjust to a pH where 100% of the respiration is inhibited (11). From these studies, it was clear that respiration consumed oxygen in the tomatoes and that no attempt to reduce oxygen in whole tomatoes was necessary.

Various pretreatments before storage of tomatoes to control oxygen did not differ significantly. Raw tomatoes were difficult to peel and keep whole if peeled after taken out of storage. Peeled tomatoes remained whole in acidified storage. This quality difference in whole tomatoes necessitates some type of peeling for the processor. Natural self peeling of the tomatoes was not dependable. A pre-peeled tomato would have faster acid infiltration and would be handled less after storage and is therefore preferred. The best way to store the tomatoes was to store peeled tomatoes in tomato juice.

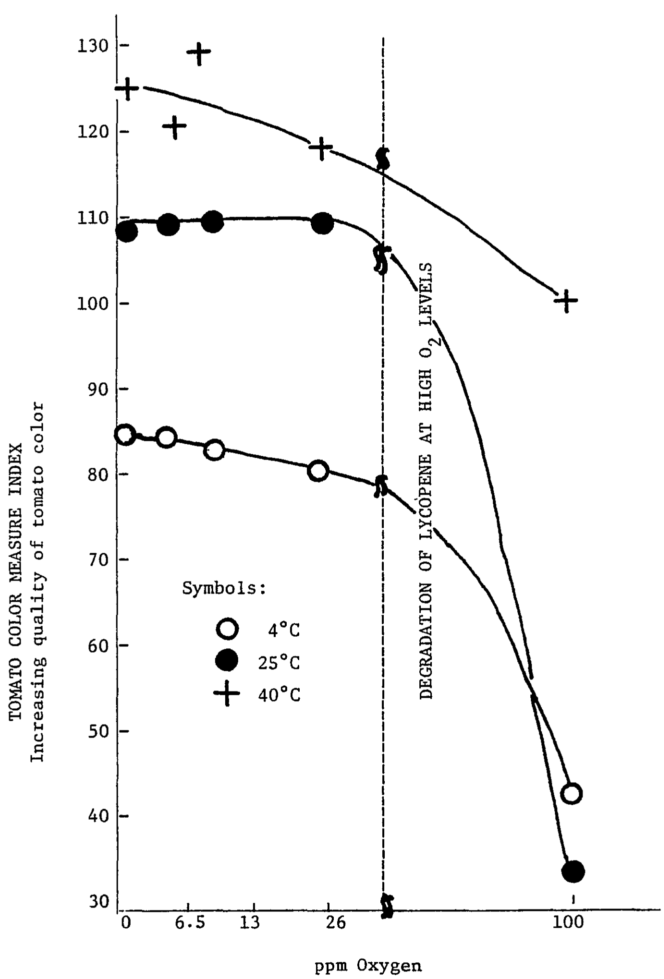


**FIG. 9.—Effects of oxygen concentration (ppm) in tomato juice on the Tomato Color Measure value at various temperatures for 3 months.**

If the tomatoes were stored in other solutions, a large amount of osmotic damage occurred, resulting in an inferior product (11).

Color and flavor deterioration were found in tomato products stored by acidified bulk storage (11). This degradation was concurrent with increases in the amounts of vitamin C and fructose present in stored tomato products. This deterioration leads to changes in volatiles and pigments that were peculiar to fructose degradation. Polymerization products appeared to be the cause of the browning. These reactions are well documented in long-term storage of tomato paste (25). The flavor and odor of these products are consistent with laevulic acid degradation. Furfural and tannin-like substances have been detected and are consistent with this pathway. Fructose is postulated to decompose into these products under very acidic conditions by a pathway proposed by Basel (11) (Figure 10). This pathway is stimulated by oxygen, high acidity, and storage length. Storage products can be monitored for off flavors by gas chromatography (Figure 11). Many of these products appeared at 30 to 50 minute retention time. These changes correlated to deterioration in flavor scores, color, vitamin C, and fructose. Current practice has succeeded in controlling these degradations sufficiently to yield good quality products for up to 3 months' storage. Better storage results are reported with products that do not have much fructose such as in some green vegetables. Fructose degradation is an important consideration in acidified bulk storage and can be minimized by using lower temperature, a shorter length of storage, and lower oxygen level while storing fruits and vegetables. This will directly lead to better color, flavor, and vitamin C retention in finished products.

One of the most important considerations in acidified bulk storage is the selection of proper cultivars. In a 1-year trial of 16 tomato cultivars, large differences were found (11). As a result of subjective color, flavor, and defect scores, the cultivars could be ranked in order of descending quality as shown in Figure 12. The cultivars Chico III and C 37 ranked below any of the other cultivars. Another important attribute was drained weight. There were large differences in drained weights after storage as shown in Figure 13. Drained weight results show the same type of cultivar trend in acidified stored tomatoes as conventionally canned tomatoes. Therefore, it can be assumed that there is no difference between the mechanisms of softening. The pH and total acidity both showed differences from cultivar to cultivar. These differences reflected a cultivar influence in buffering capacity among these cultivars. These small changes are enough to merit attention when a processor would commercially store tomatoes as buffering capacity will influence the amount of acid required. Color measurements show large differences. Tomato juice color was much poorer than the color of whole tomatoes. This may have been due to some oxygen diffusion into the storages. Defects were cultivar and temperature dependent.

There are many defects that lower the quality. Tomato cultivars with a stem scar of one-fourth inch or greater

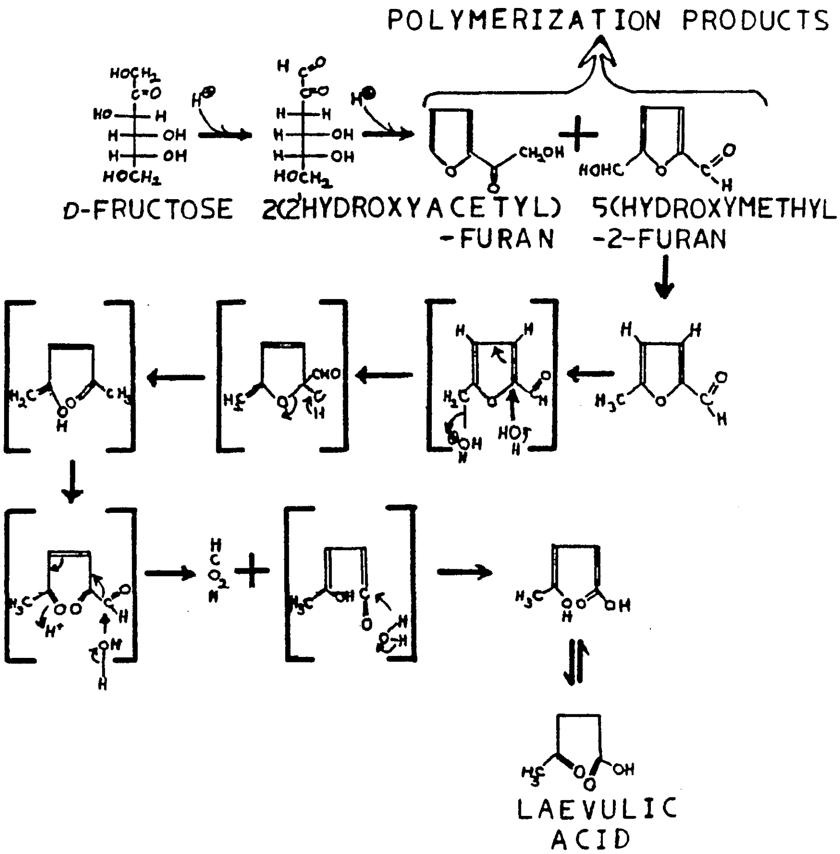


FIG. 10.—Postulated fructose degradation pathway.

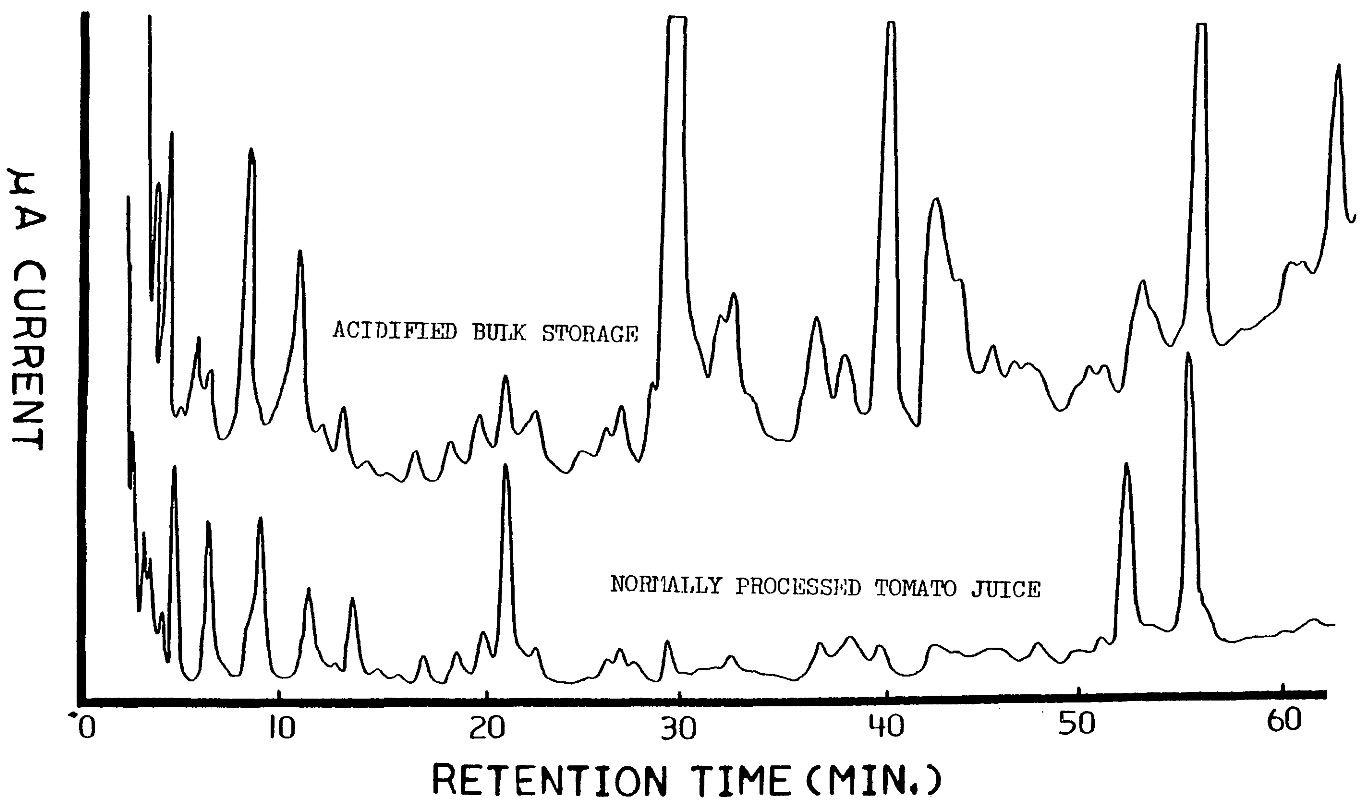


FIG. 11.—Chromatograms of volatile components from normally processed and acidified bulk stored tomatoes.

| | | | |
|---|---|---|---|
| US 141<br>VF 134-1-2<br>USDA 77B68F1<br>Heinz 414 | Best | Heinz 2567<br>97858 | Fair |
| 0781383<br>US 28<br>ONT 744-3 | Very Good | 07825<br>ONT 777<br>Kagome 5 | Poor |
| Heinz 2867<br>Heinz 2653 | Good | C 37<br>Chico III | Very Poor |

**FIG. 12.—Ranking of selected cultivars for quality after bulk storage.**

| | Drained Weight (g) | | Drained Weight (g) |
|---|---|---|---|
| US 141 | 625 | USDA 77b68F1 | 580 |
| VF 134-1-2 | 619 | 97858 | 579 |
| ONT 744-3 | 602 | 0781383 | 578 |
| Heinz 414 | 596 | Kagome 5 | 547 |
| Heinz 2653 | 593 | Heinz 2567 | 545 |
| Heinz 2867 | 593 | ONT 777 | 528 |
| 0781383 | 588 | C 37 | 520 |
| US 28 | 584 | Chico III | 435 |

**FIG. 13.—Drained weight ranking in descending order of selected tomato cultivars. Initial drained weights were 680 g.**

were considered to be a very serious defect. Any stylar scar also appeared as a defect and was most objectionable after storage. Further, the core should be as small as possible. The tomato core is a problem in whole tomato processing because a soft core is desired. Texture is another area where proper cultivar selection seems to be necessary since texture correlates with raw fruit firmness and was cultivar dependent. The parameter, percentage of soft tomatoes, also correlates to texture and firmness of raw tomatoes but not to a high degree because they are not measuring exactly the same parameter (11). Since texture was a measure of wholeness and percent of soft tomatoes was a measure of firmness, these terms are not synonymous. There was a significant decrease in wholeness associated with storage time, presumably due to crushing. It is not known what the maximum height of the storage should be to prevent crushing. Color and flavor showed concurrent deterioration and appeared to be correlated. Fructose degradation is presumed to be the cause of the deterioration of both scores.

From all experimental results, it would appear that the major problem with this storage system is fructose degradation. Further research is needed to positively identify degradation products. Other areas that are critical to the storage include oxygen exclusion from the storage and proper cultivar selection. In these experiments, spoilage was not encountered. Attention must be paid to pH in order to prevent the risk of spoilage. Microbial spoilage in acidified storage is prevented solely due to pH levels.

## State of the Art of Acidified Bulk Storage of Tomatoes

From the current knowledge, a recommended process for bulk storage of tomatoes can be formulated as outlined in Figure 14. It is recommended that whole tomatoes be conventionally washed and sorted. The recommended peeling system would be any system that would not tend to raise the pH. A chlorine dip (100 ppm sodium hypochlorite for 1 min.) prior to storage is helpful to assure control of any microbial population on the tomatoes.

The juice for the storage is manufactured from washed, sorted, and chopped tomatoes with the addition of salt. The acid should be sufficient to cause an equilibrium pH of 1.25 to 1.30 in the bulk storage of tomatoes and cover juice. The tomatoes for the cover juice should be chopped, hot broken—190° F (88° C), and extracted using approximately a 0.023 to 0.030 inch screen. Im-

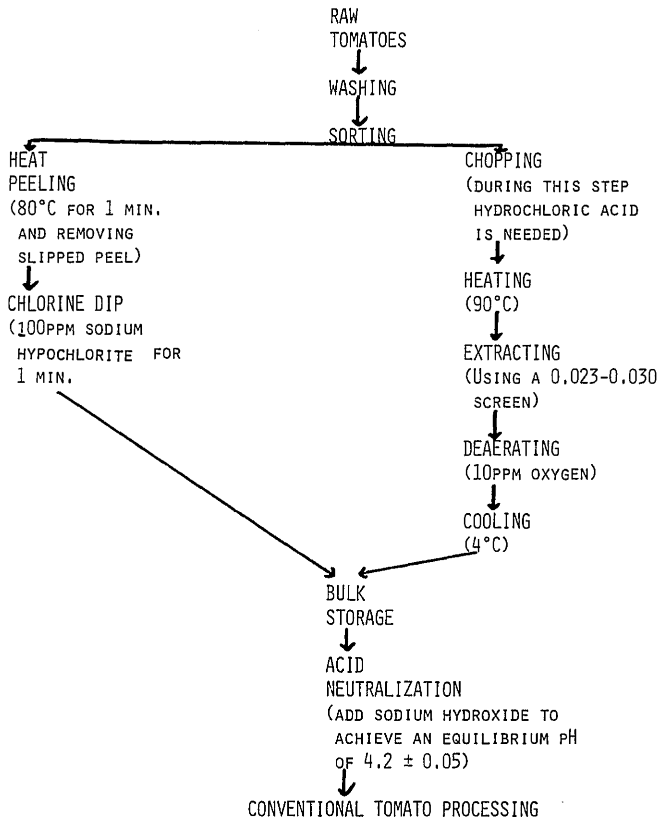


**FIG. 14.—Unit operations for acidified bulk tomato storage.**

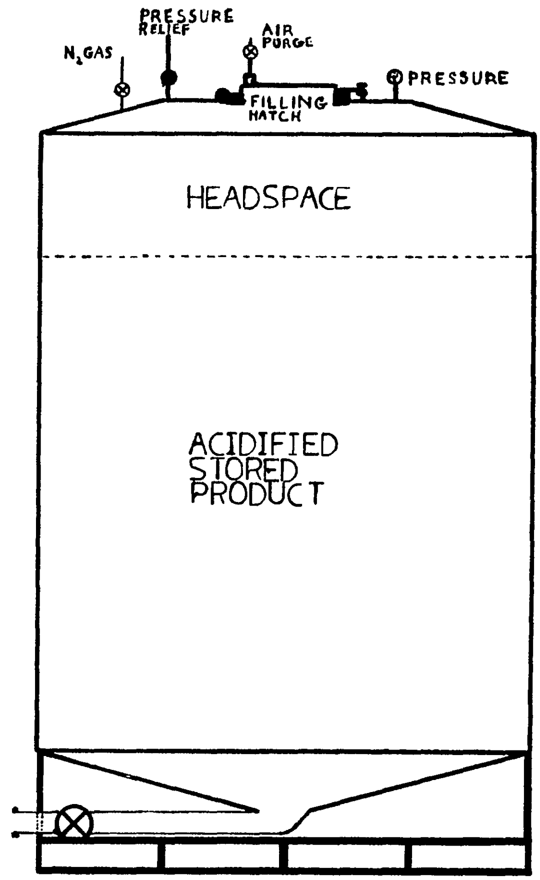


**FIG. 15.—An acidified bulk storage tank.**

mediately after extraction, the tomato juice should be cooled to 40° F (4° C) for the best results. The processor may store at ambient temperature and cool as the outside temperature changes to save money. The tanks may be plastic or of some material that is oxygen impermeable. The headscape should be nitrogen to prevent fungal growth. The tank can be outfitted as shown in Figure 15.

It is necessary to raise the pH of the tomato and cover solution after bulk storage to pH 4.1 ± 0.05 in order to use the acidified product. This needs to be done gradually or sequentially. Otherwise, there will be alkaline hydrolysis of the sugars and other components, causing darkening and rendering the product unusable. While the temperature is held low, this neutralization period does not cause problems with microbial spoilage. After the product is neutralized, it can be conventionally processed into any product desired—whole tomatoes, juice, concentrate, or others.

This method can be applied to many other products, including green beans and peas (11). Although products such as tomato juice and concentrates can be stored, aseptic storage is a better alternative due to the cost of hydrochloric acid and the absence of fructose degradation over time.

## Applications

The usefulness of the acidified bulk storage system is distinct. It has for the first time made possible the extended storage of fruits and vegetables by simple methodology. It is not susceptible to the spoilage problems of post-harvest aseptic storage systems. While this method needs further research, it holds special promise to the food processor. Acidified bulk storage allows the processor total flexibility to produce whatever end product is needed in the case of tomatoes. As of 1979, it was calculated that the projected costs of chemicals would amount to between $10 and $20 per ton of tomatoes stored. This would be competitive with aseptic storage because much of the cost is defrayed by the large initial capital investment cost of aseptic storage systems. In addition, this type of storage could be performed on a large or small scale. The only change would be in pH measuring equipment, and acid resistant materials where the acidified product contacts equipment such as metering pumps for acidifying and neutralizing the product and storage tanks. These are much less expensive for the processor than an aseptic bulk storage that takes a huge capital investment.

It would seem that with the present techniques, this process will allow the production of a good quality product. Beyond that, more research is needed for products containing high concentrations of fructose. Many of the products stored in the course of this study showed sufficient quality to merit use as an added component to foods where it would not be used as the major component.

This method has shown many interesting results that merit further study. It also can be applied to other fruits and vegetables with success. It has been shown that acidified bulk storage has good potential and may be best suited for the processor who already uses aseptic storage of concentrates. Both systems may complement a processor's ability to remain competitive in the future. It is hoped that this project will continue to show economic feasibility and eventually be used by the industry.

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